MASTER OF SCIENCE
IN
APPLIED MATHEMATICS

AN ANALYSIS OF THE TACTICAL UNMANNED VEHICLE DURING AMPHIBIOUS ASSAULT COMBAT OPERATIONS USING THE JCATS COMBAT MODEL

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The Unmanned Ground Vehicle (UGV)/System Joint Project Office is currently developing a family of unmanned ground systems that may have the potential to give the ground combat commander the ability to gain a decisive advantage in the battle for information dominance. By harnessing the power of robotics in a reconnaissance, surveillance, and target acquisition role, the UGV is designed to provide the maneuver battalion commander with the ability to extend his influence beyond the capabilities of traditional scouts.

This thesis examined the Unmanned Ground Vehicle Medium (UGVM) using the Joint Conflict and Tactical Simulation (JCATS) model to evaluate the impact of changes to performance characteristics of the system. The scenario used for the simulation was based on Exercise KERNEL BLITZ (KB), a biennial joint amphibious operation conducted on the West Coast of the United States.

The UGVM's communication limitations and speed were varied in the JCATS simulations. Measures of effectiveness (MOEs) for these changes included total blue detections, blue detections over time, total blue kills, and blue losses over time.

DoD KEY TECHNOLOGY AREAS: Command, Control, and Communications, Electronics, Sensors, Ground Vehicles, Modeling and Simulation

KEYWORDS: JCATS, Unmanned Ground Vehicles, Amphibious Combat Operations

HIGH RESOLUTION MODELING OF A TERRORIST CHEMICAL ATTACK IN AN URBAN AREA

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This thesis demonstrates the use of Janus in modeling Military Operations Other Than War (MOOTW). Janus has many uses throughout the United States military. Lately, MOOTW have become a major percentage of the U.S. military's efforts. Using Janus to model these operations can help predict casualties, determine if new pieces of equipment make a difference in the operation, and help evaluate "what ifs" in operations. More importantly, conducting a simulation before carrying out an actual exercise saves money and people's time and effort. The threat of a terrorist chemical attack is a very likely event in this day as demonstrated by the 1995 chemical attack in a Japanese subway. Current U.S. policy has allocated certain resources to assist local governments in the event of an emergency. Unfortunately, these assets can't immediately respond to a chemical crisis. Time waiting for these assets to arrive must be spent wisely to save lives. Local governments do not all have the same capabilities available to respond to a chemical

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attack. Using a high resolution combat model such as Janus at the local level will help determine assets that will save lives and money.

DoD KEY TECHNOLOGY AREAS: Chemical and Biological Defense, Modeling and Simulation

KEYWORDS: Janus, Sarin, Terrorism, HPAC Model, Military Operations Other Than War (MOOTW), Hypothesis test, Goodness-of-Fit-Test

A MATLAB GRAPICAL USER INTERFACE (GUI) FOR A LEGENDRE PSEUDOSPECTRAL ALGORITHM FOR OPTIMAL CONTROL PROBLEMS

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This implementation of a Legendre-Gauss-Lobatto Pseudospectral (LGLP) algorithm takes advantage of the MATLAB Graphical User Interface (GUI) and the Optimization Toolbox to allow an efficient implementation of a direct solution technique. Direct solution techniques solve optimal control problems without solving for the optimality conditions. Using the LGLP method, an optimal control problem is discretized into a Nonlinear Program (NLP) and solved using an NLP solver, avoiding the problems of deriving the conditions of optimality and solving the resulting boundary value problem. The MATLAB GUI implementation solves optimal control problems without requiring knowledge of the specific implementation of the LGLP method. The GUI completes the discretization of the problem and solves the resulting NLP using a Sequential Quadratic Programming Algorithm. The GUI will convert any optimal control problem with fixed, free or optimal final time, a Mayer, Lagrange or Bolza cost function, constrained or unconstrained controls, with or without state inequalities, and point inequalities into a parameter optimization problem and returns a solution. The GUI creates a function file, output file, binary save file, and optimization script to allow full access to the strength of the LGLP method from the GUI or the command line. No prior knowledge of the LGLP algorithm is assumed or necessary.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Computing and Software

KEYWORDS: Direct Methods, Optimal Control Theory, Calculus of Variations, MATLAB, Nonlinear Programming, Optimization

LEAST SQUARES SOLUTIONS IN STATISTICAL ORBIT DETERMINATION USING SINGULAR VALUE DECOMPOSITION

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This thesis is a partial analysis of the Naval Space Command statistical orbit determination algorithms. Through a process called Differential Correction, data from space surveillance radar observation stations are synthesized with previously accumulated element sets to maintain accurate orbital object position information. Differential Correction is a nonlinear least squares process employing statistical techniques to minimize the residual measurement error thereby increasing relative position information accuracy. This study focuses specifically on the algorithmic methods of solution to the systems of normal equations generated by the Differential Correction process. A comparison and analysis of the present Naval Space Command method and the singular value decomposition method is presented. Algorithmic constructions are presented for both methods and problematic areas are highlighted. The principal focus herein is to demonstrate the benefit of singular value decomposition when attempting to solve systems of equations

whose coefficient matrices are dense and nearly singular. These results generalize to commonly employed normal equation solution algorithms and are intended for further study and possible incorporation by Naval Space Command as part of future modernization plans.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Computing and Software

KEYWORDS: Least Squares, Nonlinear Least Squares, Normal Equations, Singular Value Decomposition, Gaussian Elimination, Differential Correction

ANALYSIS OF THE NECKLACE ALGORITHM AND ITS APPLICATIONS

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A commonly studied problem in the field of cryptography is the Discrete Logarithm Problem. This problem is also referred to as the "distance" problem. Basically, one would like to know where a particular binary n-tuple is in a list combining all of them, represented as powers of some primitive element, or equivalently what is the distance between a given pair of n-tuples in a similar representation. A de Bruijn sequence is a well-known periodic binary sequence in which every n-tuple from 0 to 2^n-1 appears. Our goal is to better understand the "prefer-ones" de Bruijn sequence. Ultimately, we wish to understand where each of the binary n-tuples appears in that sequence. Using the Necklace Algorithm, the sequence of n-tuples can be generated. This list has some special properties that allow us to perform the required analysis to locate the n-tuples by an association into classes. We partition the binary n-tuples into necklace classes according to the longest substring of ones appearing on the n-tuple. We then count how many n-tuples appear in the sequence for the first time as members of a necklace class containing no longer strings of ones.

DoD KEY TECHNOLOGY AREA: Other (Cryptography, Discrete Mathematics, Combinatorics)

KEYWORDS: Discrete Mathematics, Combinatorics, Necklaces, Lyndon Words

STATISTICAL ANALYSIS OF ATMOSPHERIC PROPERTIES FOR ESTIMATION OF INFRARED RADIANCE OF BALLISTIC MISSILES

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Missile defense systems currently under development rely on thermal Infra-Red (IR) seekers to detect and track incoming ballistic missiles. Atmospheric properties, like temperature and density, can greatly affect the amount of IR energy that is reflected off a targeted missile.

While many models to predict mean atmospheric conditions exist, there are no global models that account for the variability in these properties. This shortcoming makes it difficult to assess uncertainty due to atmospheric conditions.

For this reason, a model that is adjusted for known extreme values is needed for use in describing the global behavior of atmospheric parameters. This study is in support of MSIC's development of a Bounded Earth Atmospheric Model (BEAM). This study will attempt to create such a model through statistical analyses on an existing atmospheric model. It is expected that BEAM will primarily be used by designers of IR sensors used in missile defense systems.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Sensors, Other (Missile Defense)

KEYWORDS: Missile Defense, Atmospheric Model, Infrared Radiance, Density Estimation